MIT's Utility of the Future Study

How will electricity services will be provided in 2030, with a focus on the role of distributed energy resources (DERs) in a changing electricity landscape?

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The MIT Utility of the Future Study…

- … examines how distributed energy resources (DERs) are **changing the provision of electricity services**,
- and makes **policy, regulatory and market recommendations**…
- … to facilitate an efficient, low carbon emission energy system that **encourages optimal utilization of resources** whether centralized or decentralized.

Study Contributions

- Recommendations to **remove inefficient barriers to harnessing cost-effective DERs**. In particular, a set of **proactive regulatory reforms** to align distribution utility incentives and responsibilities for a more distributed future.
- **A framework for cost-reflective prices and charges for electricity services** that will let the best solutions emerge in an uncertain future.
- A **set of insights** about the economics of DERs and the competition between DERs, conventional generators, and traditional network investments.

Removing Barriers to Cost-effective DERs

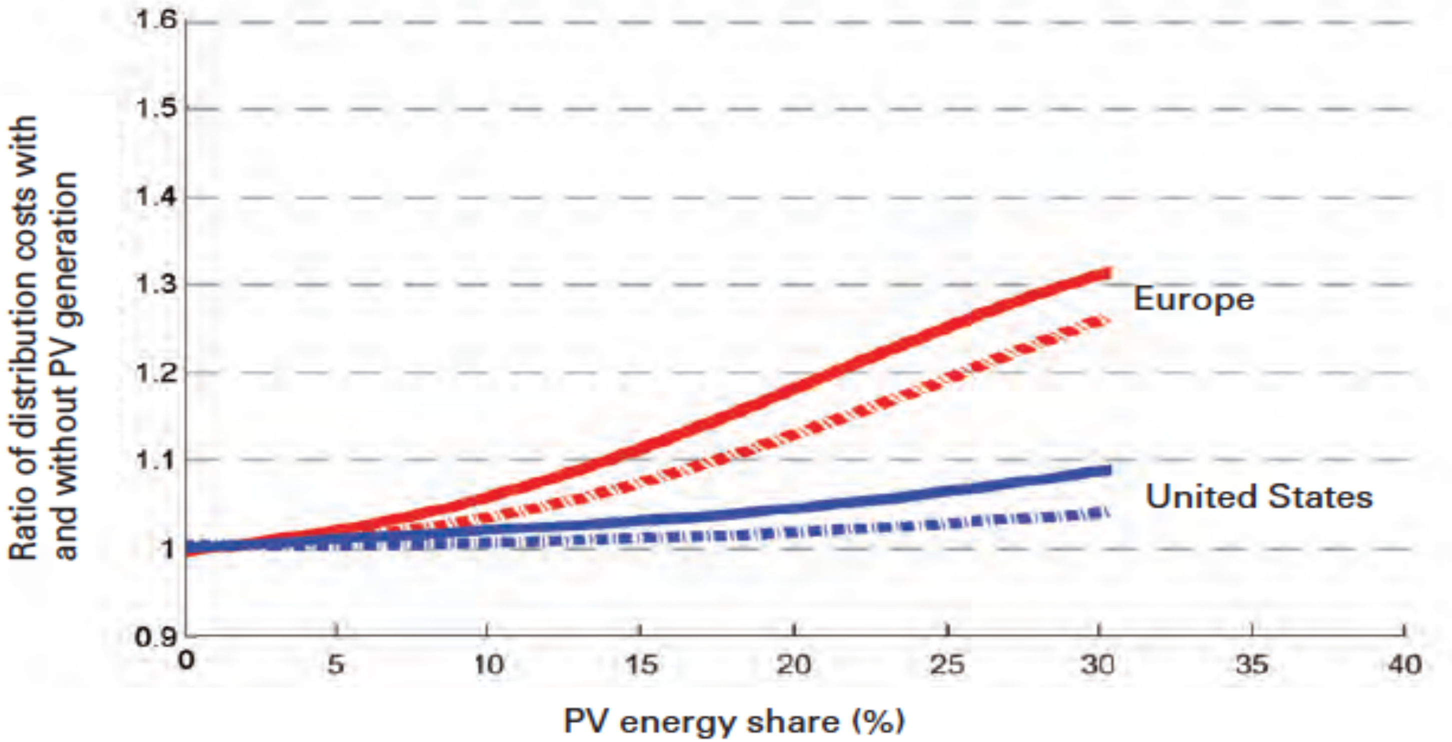
Barriers to DER participation

- **Regulations of distribution networks** that are ill-adapted to a world with DERs
- **Industry structures** that may result in a tilted playing field against new business models harnessing DERs
- Biased or inadequate **wholesale market rules** that impede the full participation of cost-effective DERs or limit their potential competitive performance.

Distribution regulation

From the MIT "Future of Solar Study"…

Changes in network costs with growing PV penetration



These curves show the impact of solar generation on distribution network costs in the United States (blue) and in Europe (red). (Results differ in part due to differing network configurations and voltages.) Costs are measured relative to the cost of a corresponding no-PV scenario. Energy storage is assumed to be unavailable. Solid lines indicate 80% residential, 15% commercial, and 5% industrial demand. Dashed lines indicate 15% residential, 80% commercial, and 5% industrial demand. In all cases, costs increase as PV energy share increases, with the greater impact seen when residential customers dominate demand.

The regulated network utility business model

"New business models" really means new regulation. 6 priorities…

1. A forward looking revenue trajectory
   - The future does not look like the past
2. Efficiency incentives via earnings sharing mechanisms
   - Align utility's business model with finding new solutions
3. Equalize incentives between OPEX and CAPEX
   - Put "wires" and "non-wires" solutions on a level playing field
4. Create mechanisms to adjust for inevitable forecast errors
   - Manage uncertainty, improve regulatory certainty and allocative efficiency
5. Set performance-based incentives for quality of service
   - Reward utilities for delivering better service & achieving policy objectives
6. Create incentives for long-term innovation
   - Accelerate learning about capabilities and diffusion of best practices

Industry structure

Distribution Network Owner/System Operator (DNO/SO)

Responsible for network provision, system operation, distribution-level market platforms (as needed).

Structurally independent of competitive market segments (retailing, DERs, wholesale)

Functional unbundling second-best option

Parallels TSOs in Europe

Independent Distribution System Operator (IDSO)

Independent entity responsible for network planning, system operation, distribution-level market platforms (as needed).

Wires co.s responsible for network construction & maintenance, may be vertically integrated into competitive market segments)

Parallels ISOs in US

Sub-transmission System Operator (StSO)

Independent entity responsible for planning, system operation, market platforms down through meshed portion networks (e.g. ~12 kV)

Appropriately regulated distribution utilities remain responsible for medium & low voltage distribution.

Could be an “extended” ISO, capturing economies of scope with bulk system operation

Closely-regulated Vertically-integrated Utility

Incorporate all critical functions within single utility vertically integrated with other segments such as retailing or generation

Requires close regulation, appropriate incentives to mitigate vertical foreclosure

Improved version of “status quo” in many jurisdictions

Wholesale market reform

Barriers to DERs participation in wholesale markets

Wholesale and ancillary service market reforms

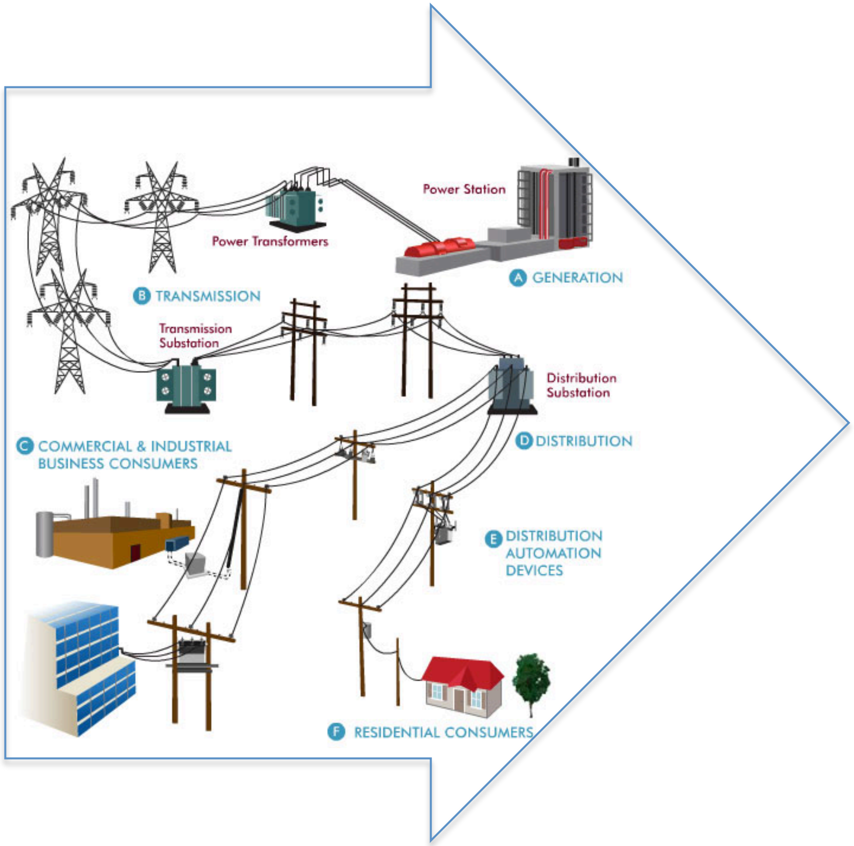
1
- Moving to **intraday prices closer to real-time** to unlock and reward greater flexibility

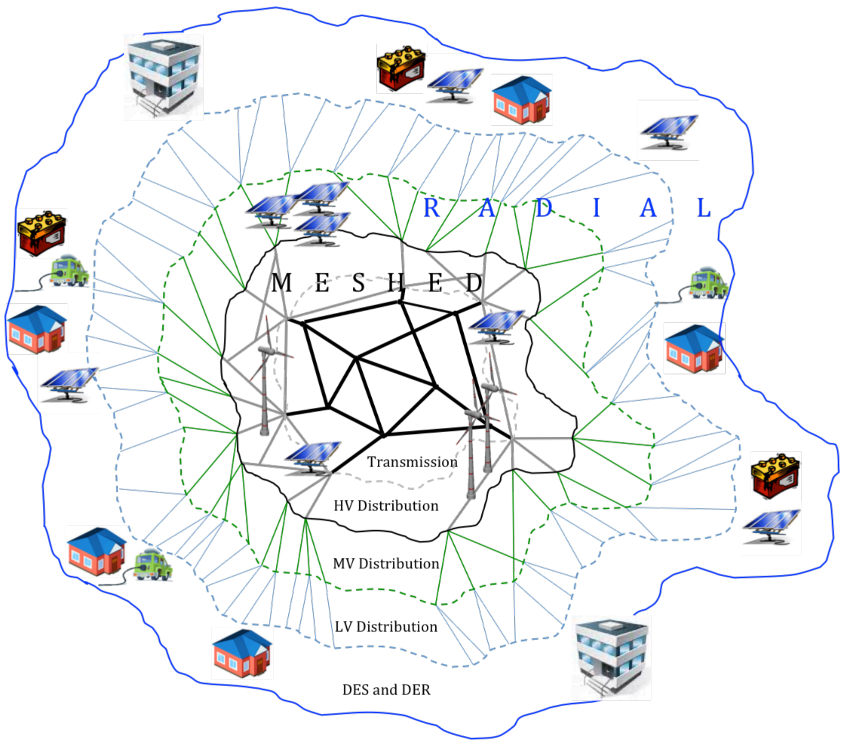
2
- Updating bid formats to allow **more complex formulations of constraints** (e.g. flexible demands, storage, EV charging fleets)

3
- **More efficient pricing of reserve products** (make sure that scarcity situations are reflected in prices) and non-discriminatory rules for participation of DERs or DER aggregations in reserves markets

Getting prices & charges right to let the best solutions emerge

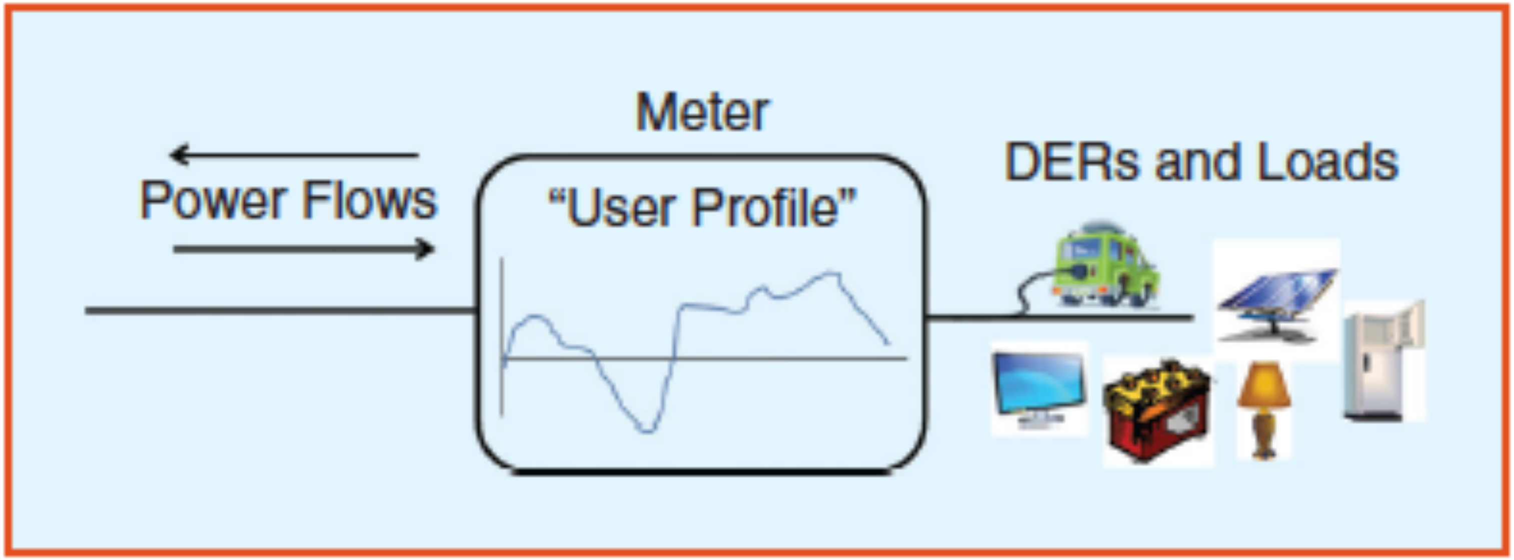
A change of mindset





"Technology neutrality"

Any cost-reflective component of prices & charges should be exclusively based on the individual injection & withdrawal profiles at the network connection point



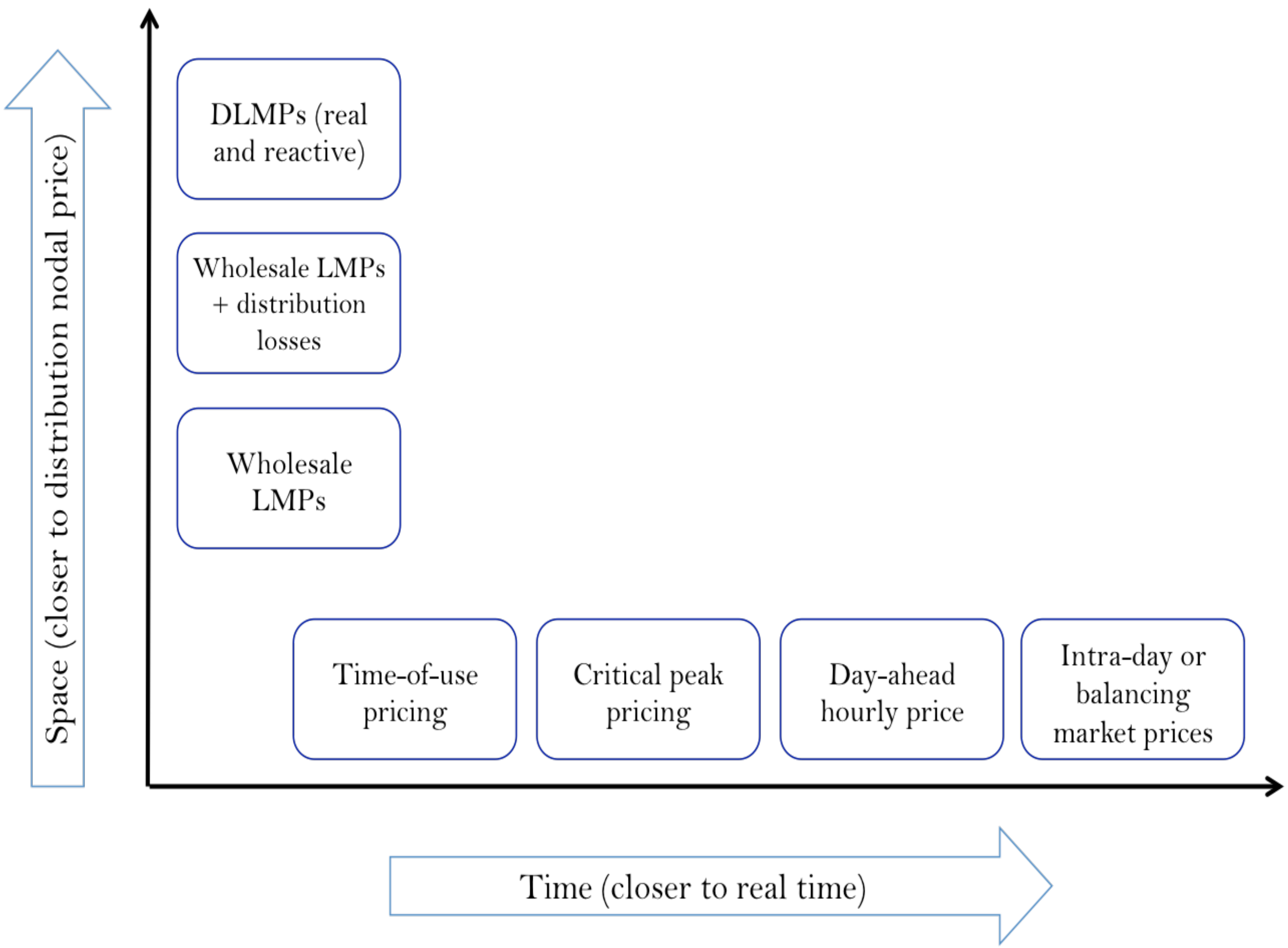
Spatial & temporal granularity matters

The design and the level of time and locational differentiation of electricity prices and charges have a substantial impact on the efficiency of DERs response and their impact on networks and centralized generation

This also applies to the volume and format of allocation of policy charges in electricity tariffs, which can be a contributing factor to grid defection

Improving the design of prices & charges

How far to go in time and location differentiation will depend on the trade-off between efficiency gains and implementation cost



Possible progression of time and locational granularity of energy price signals

Getting Prices Right: Short-run marginal costs

Wholesale locational marginal prices

- Captures marginal cost of energy, transmission congestions and transmission losses, and if reserves are co-optimized, the impact of reserves on energy prices as well
- Could be extended to end of “meshed” network at medium voltage substations

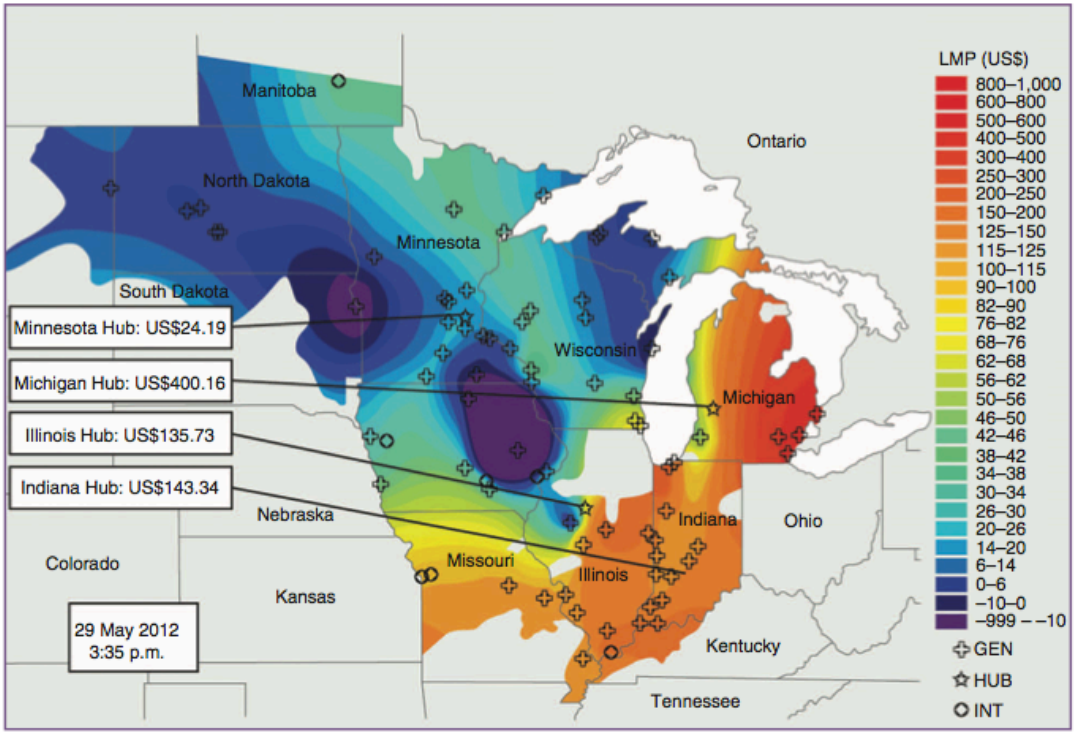


figure 8. A sample of LMPs in the Midwest ISO system (courtesy of MISO).

Getting Prices Right: Short-run marginal costs

LMPs with distribution losses

- Estimated or metered load losses in distribution networks
- Rise quadratically with power flows, so can be significant marginal cost during high load hours (e.g. 20-40%)

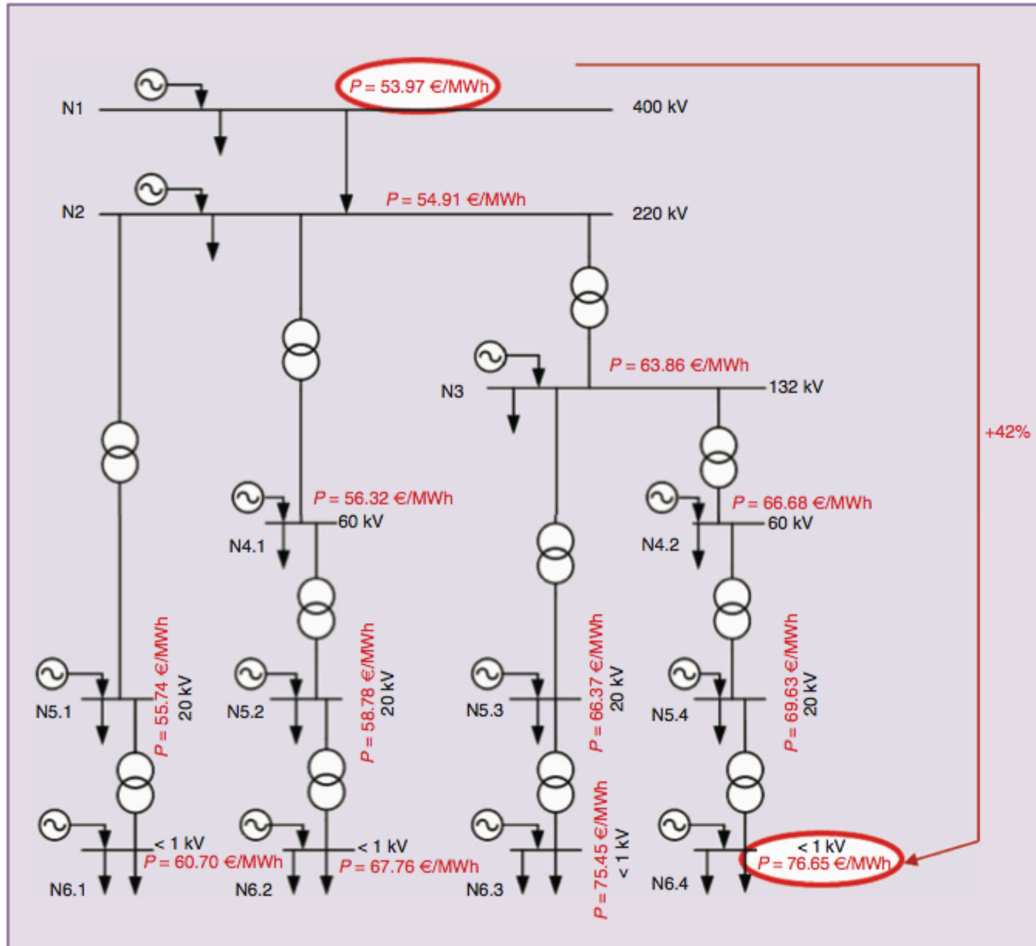
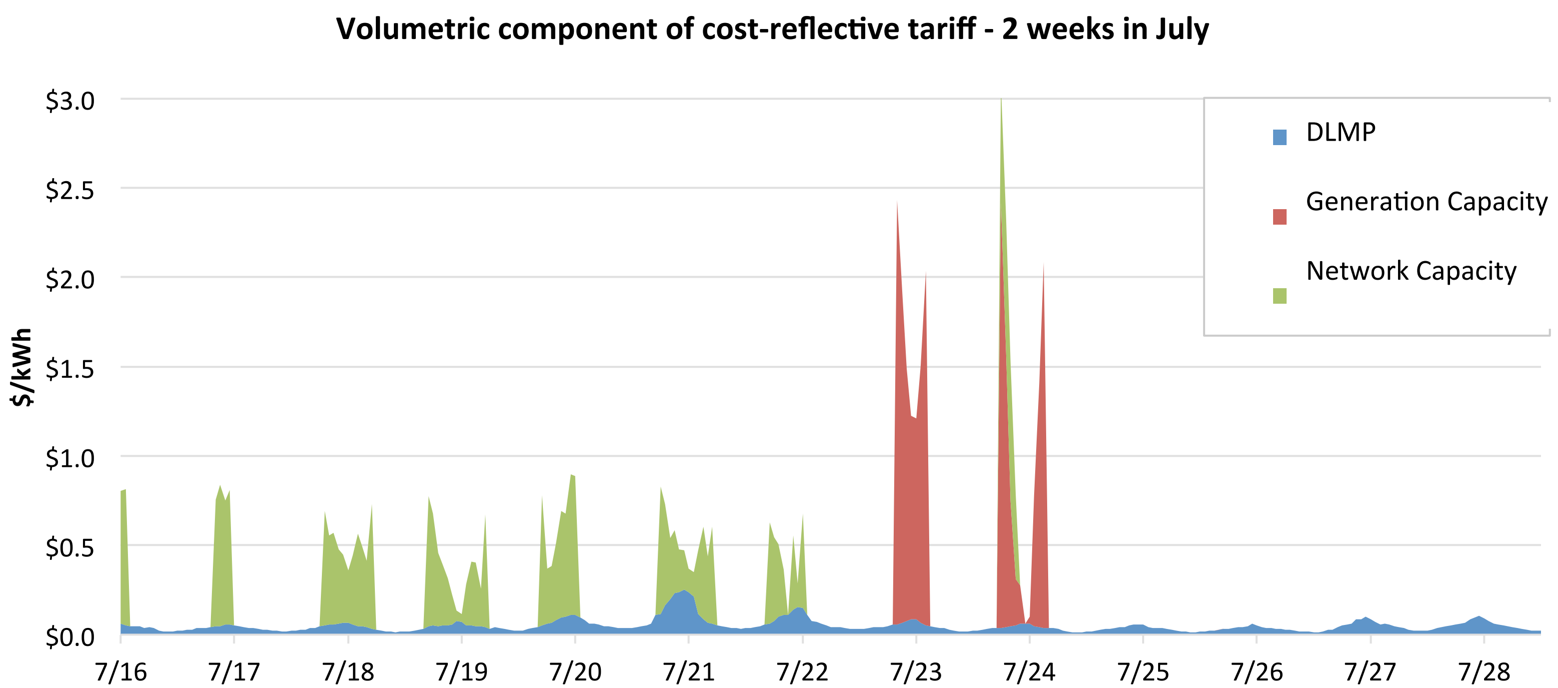


figure 9. Distribution LMPs considering aggregated distribution losses for the Spanish system.

Source: Pérez-Arriaga, *IEEE Power & Energy Magazine* (2016)

Getting Prices Right: Long-run incremental costs

Step 4. Peak-coincident consumption and injection charges can signal the incremental cost of investment in network and generation capacity, allowing distributed users to embrace DERs and flexible demand where cost-effective alternatives.



Example cost-reflective tariff for Westchester, New York; Source: Huntington & Jenkins, MIT *Utility of the Future* study (forthcoming)

Getting Prices Right: Short-run marginal costs

Distribution locational marginal prices (DLMPs)

- Real and reactive locational marginal prices computed throughout distribution networks
- Captures thermal and voltage constraints
- Requires new advances in computational solutions to be tractable (e.g. distributed proximal message passing, new decomposition techniques)

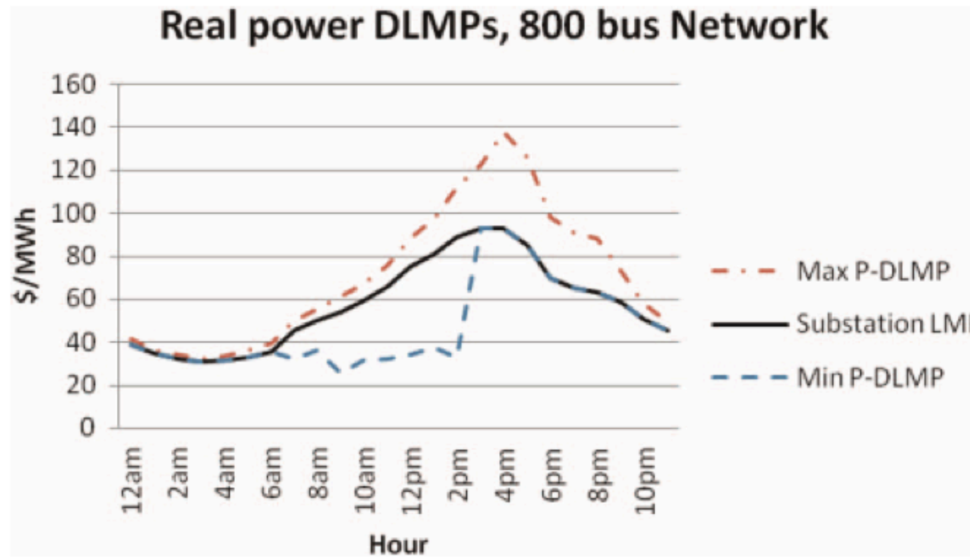
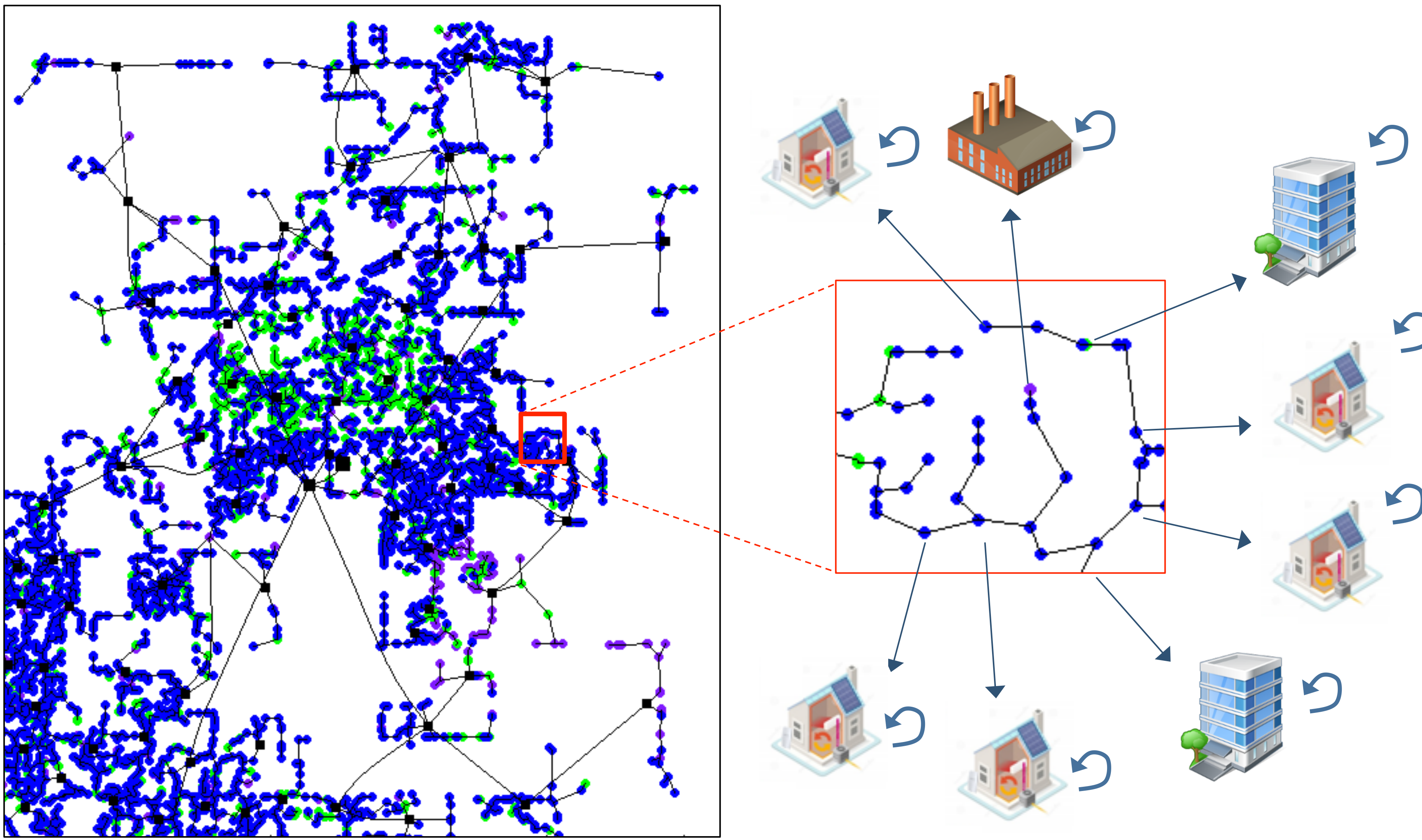


Fig. 14. ***Minimum, maximum, and substation real power DLMP for an 800-bus distribution network with high distributed energy resource penetration.***

Source: Caramanis, et al., *Proc. of the IEEE* (2016)

Accounting for the response of the end network user



How to compute network charges?

Getting Prices Right: Distribution network charges

Objectives of network charges: 1) Send efficient economic signals beyond DLMPs (if they exist); 2) contribute to the recovery of regulated network costs; 3) remaining regulated costs should be recovered in a minimally distortive manner (perhaps outside the tariff)

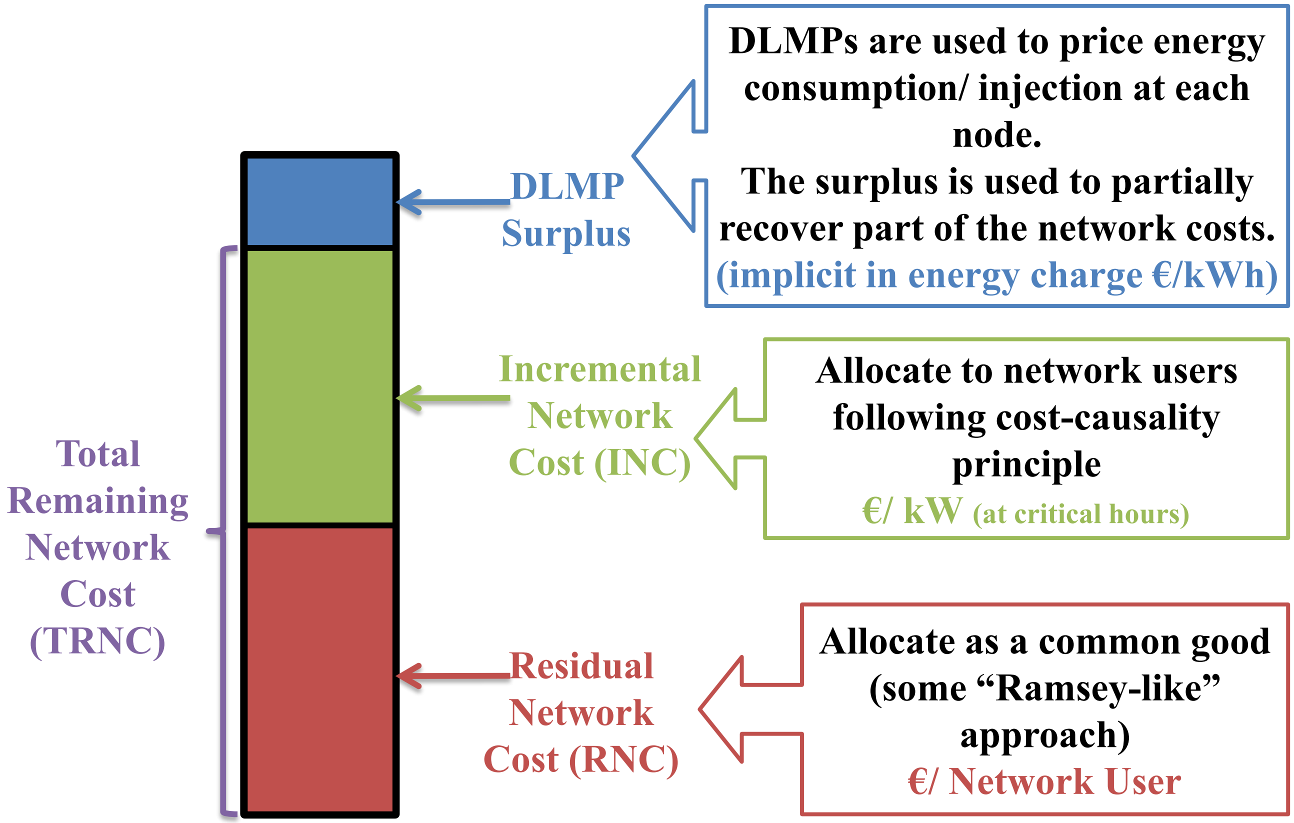
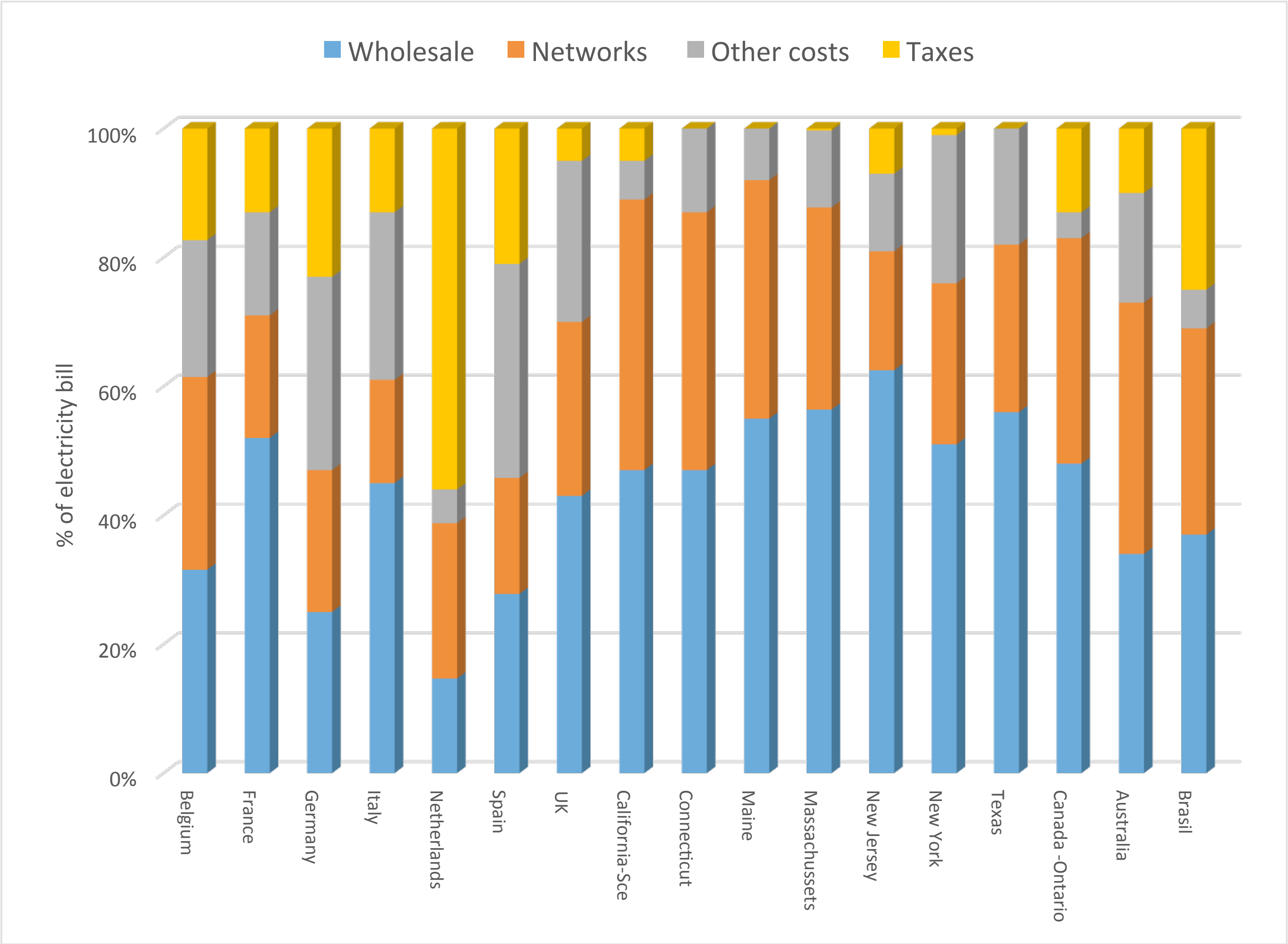


Figure: Components of network cost recovery

Policy costs

Policy costs

Avoid interference of policy charges on energy & market signals
We need to remove them from tariffs &/or be “very creative”

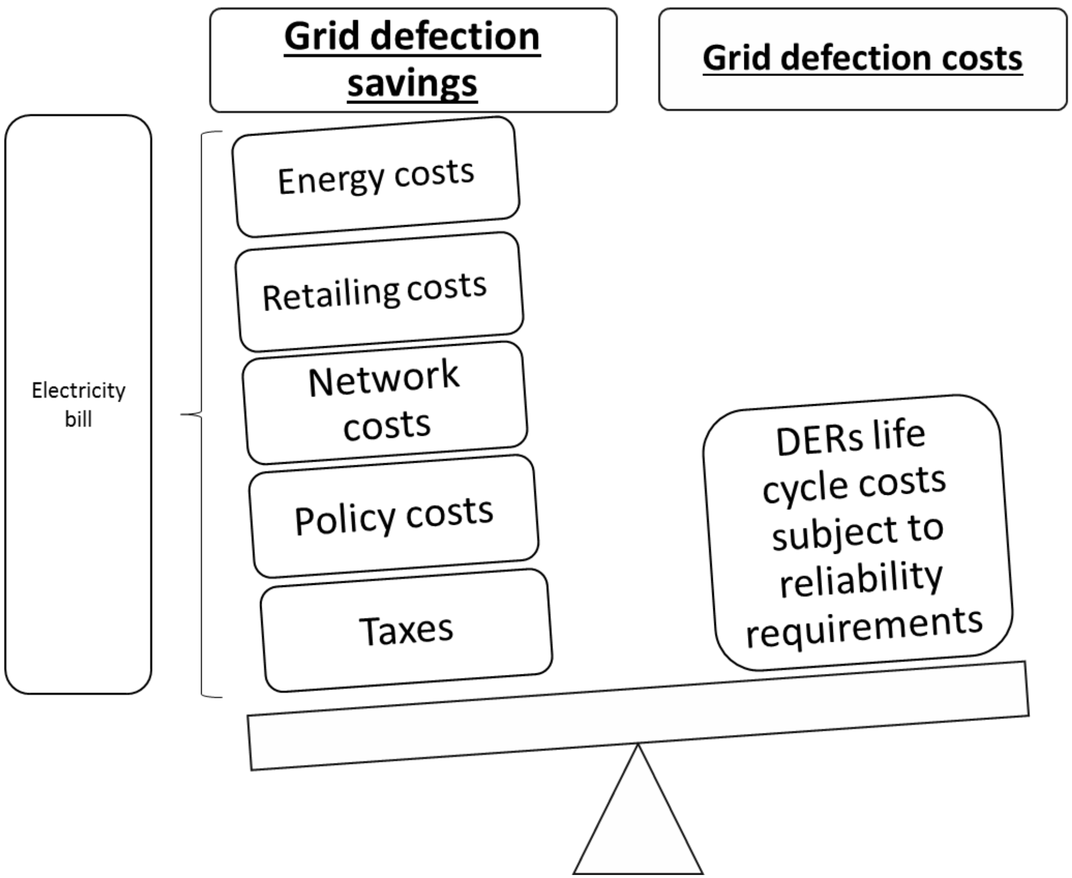


Breakdown of residential electricity bills in different jurisdictions in 2014-2015

Implications on grid defection

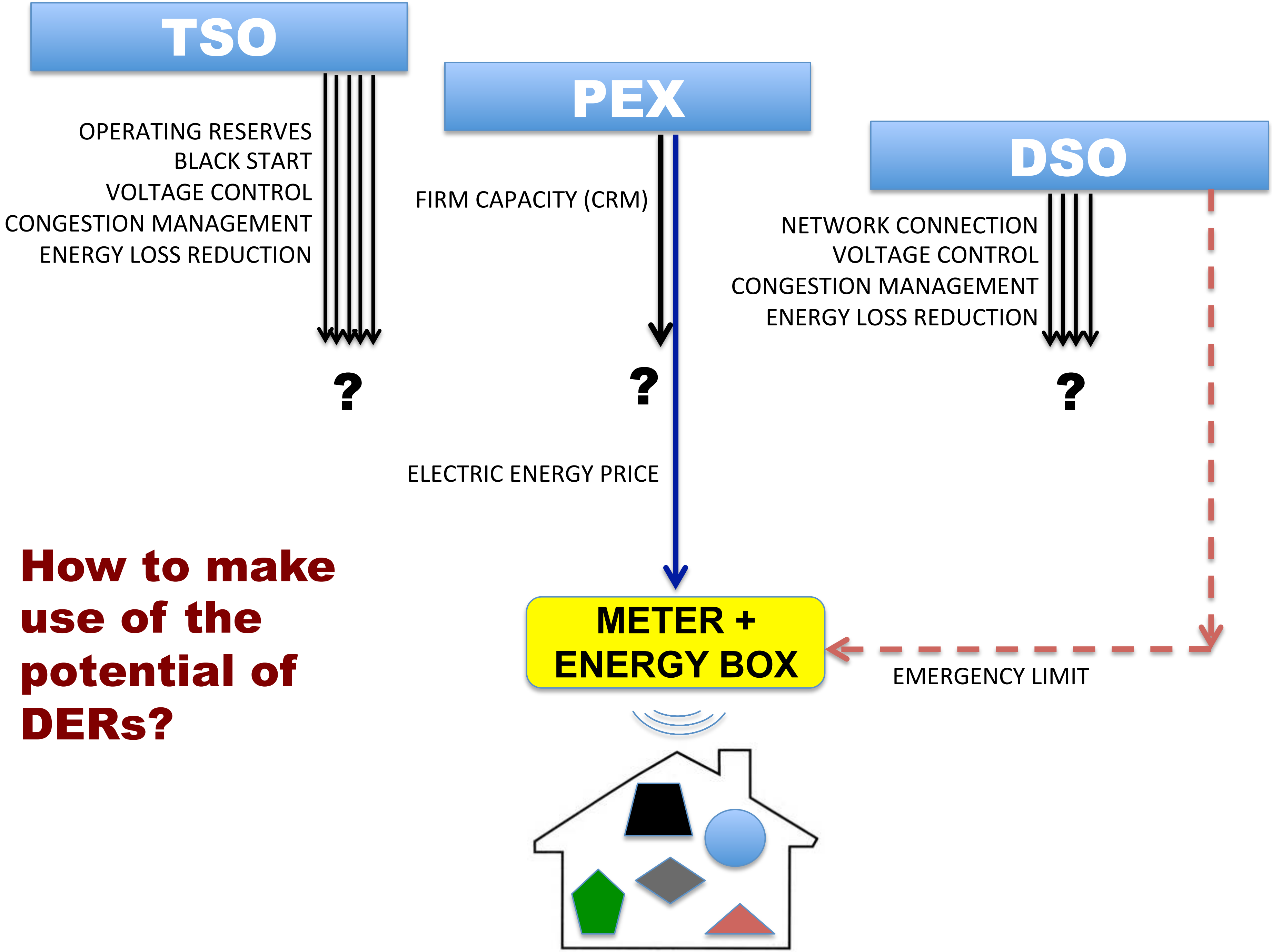
Getting Prices Right: Implications on grid defection

Cost recovery in an era of "grid defection" — the marginal cost to customers of "grid defection" creates an upper limit on the recovery of regulated and policy costs via fixed charges



How much time / locational / service granularity?

How much should the toaster know?
Is it worth sending prices & charges to it?


TSO
PEX
DSO
OPERATING RESERVES
BLACK START
VOLTAGE CONTROL
CONGESTION MANAGEMENT
ENERGY LOSS REDUCTION
FIRM CAPACITY (CRM)
NETWORK CONNECTION
VOLTAGE CONTROL
CONGESTION MANAGEMENT
ENERGY LOSS REDUCTION
?
?
?
ELECTRIC ENERGY PRICE
How to make use of the potential of DERs?
METER + ENERGY BOX
EMERGENCY LIMIT

Locational value of DERs
Concepts & a case example

Then why distributed? – Distributed energy resources can deliver a broad suite of benefits to the power system, some site specific and some system wide. Locational values may add sufficient value to justify distributed opportunity cost

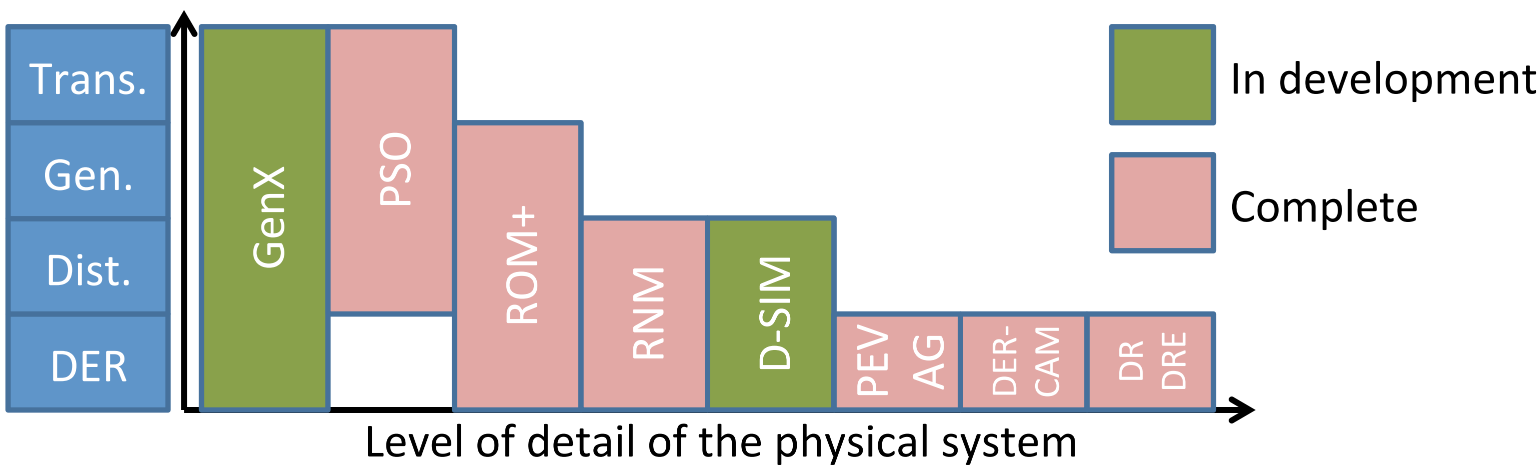
	Locational	Non-locational
Power system benefits	– Network capacity – Network constraint mitigation – Loss reduction – Voltage control – Power quality – Reliability and resiliency	– Energy (excluding losses and congestion) – Firm capacity – Operating reserves – Price suppression – Price hedging
Other public benefits	– Land use – Employment	– Emissions mitigation – Energy security

Source: MIT Analysis

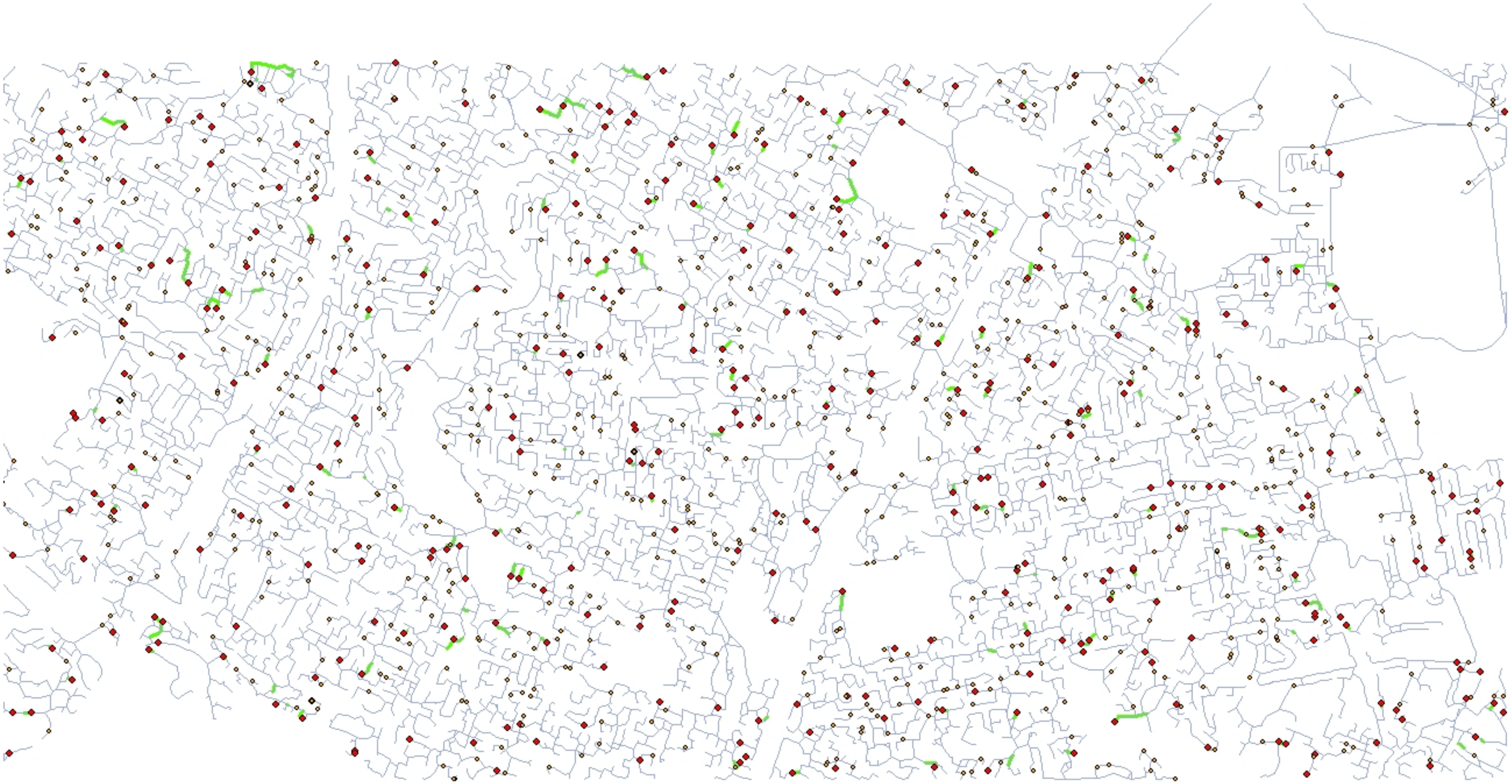
Our computer models

The computer models that we have used

- Portfolio of models covering the entire power system
  - **DR DRE & DER-CAM** (price-taker DER optimization) & **PEV AG** (electric vehicles): Operational
  - **RNM** (Distribution network planning): Operational
  - **D-Sim** (Distribution network simulation for DLMP calculation): Development
  - **ROM+** (UC & ED with network representation): Operational
  - **PSO** (UC & ED with network representation): Operational
  - **GenX** (capacity expansion with DERs): Development



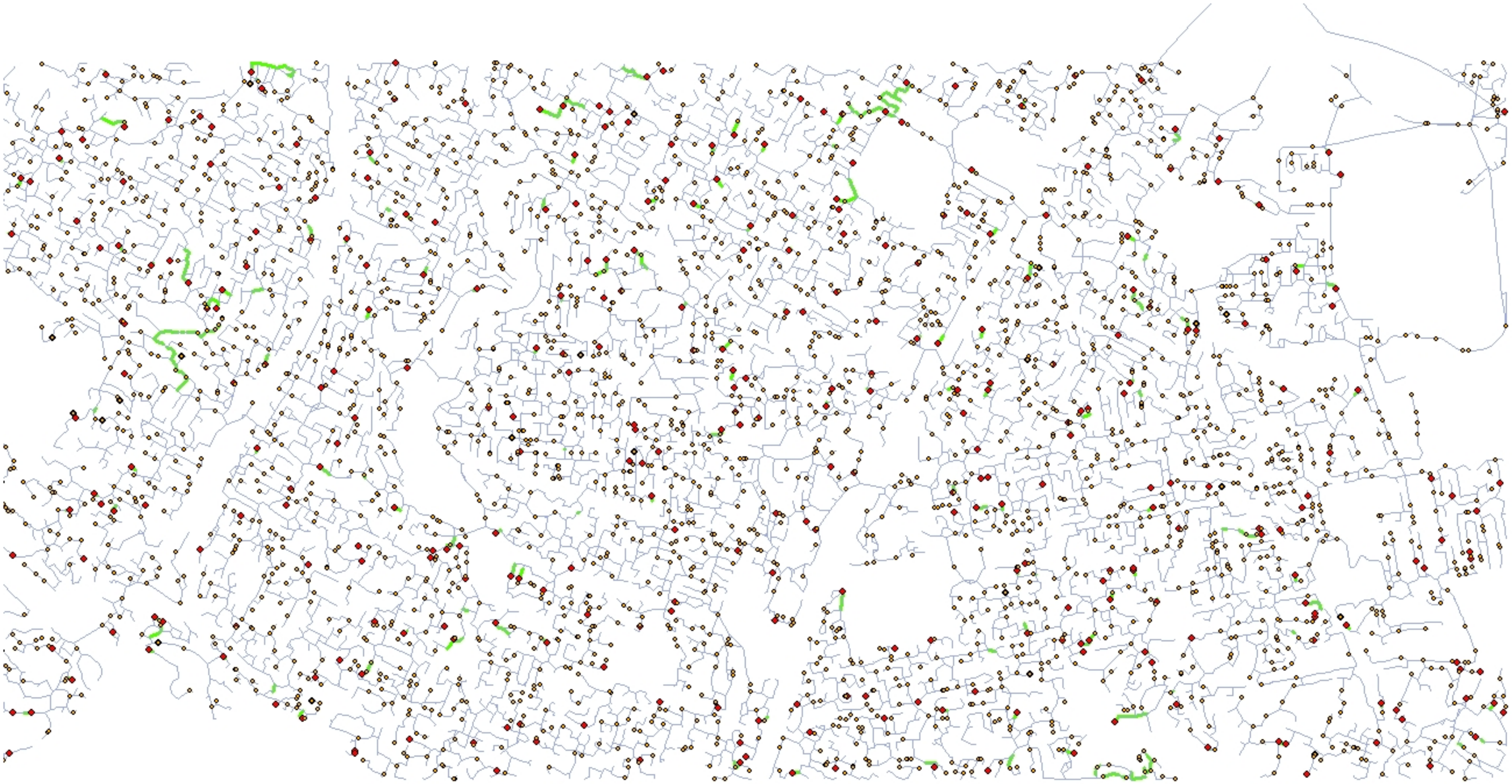
Reference Network Model



Source: MIT Solar Study

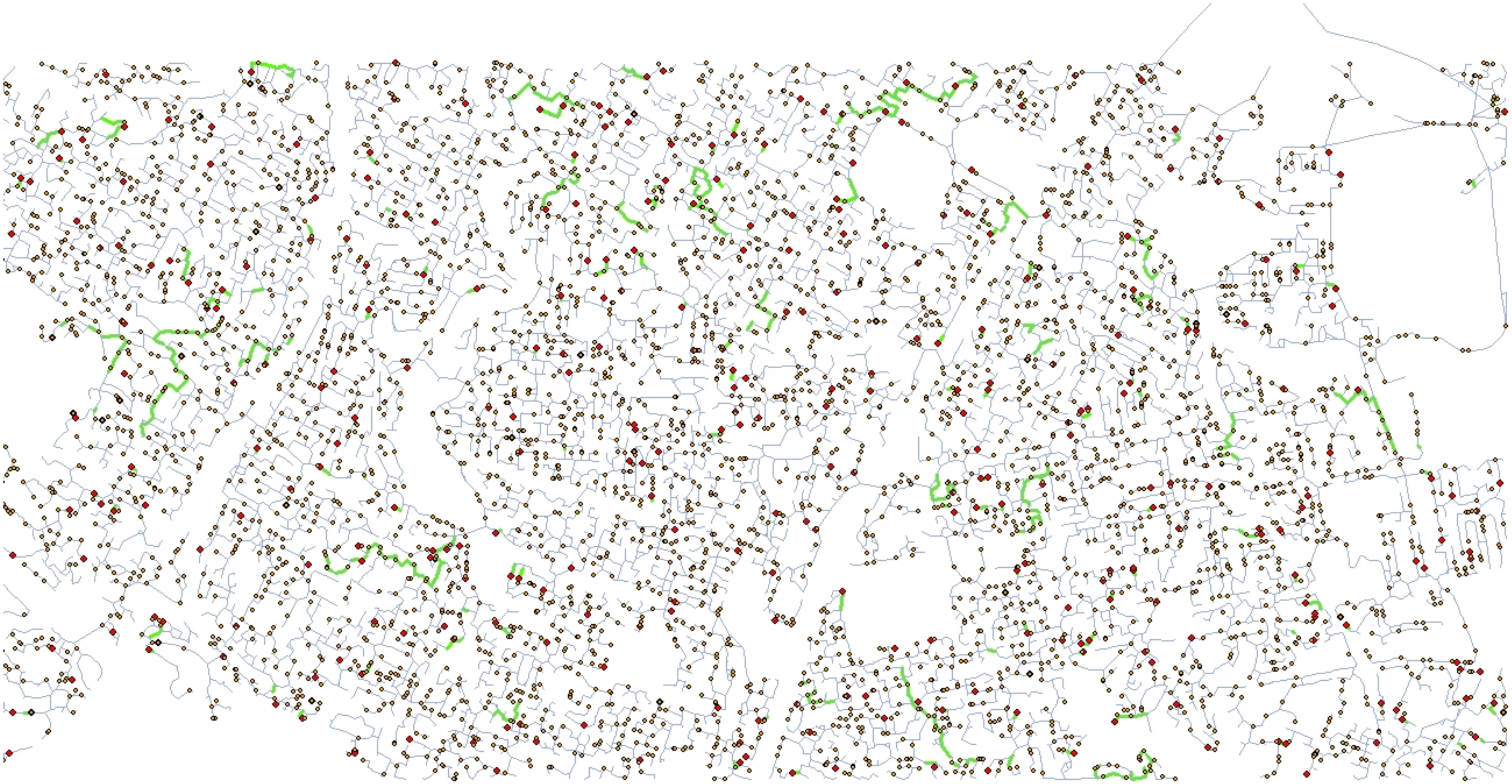
(*) Model RNM developed by IIT-Comillas University

Reference Network Model



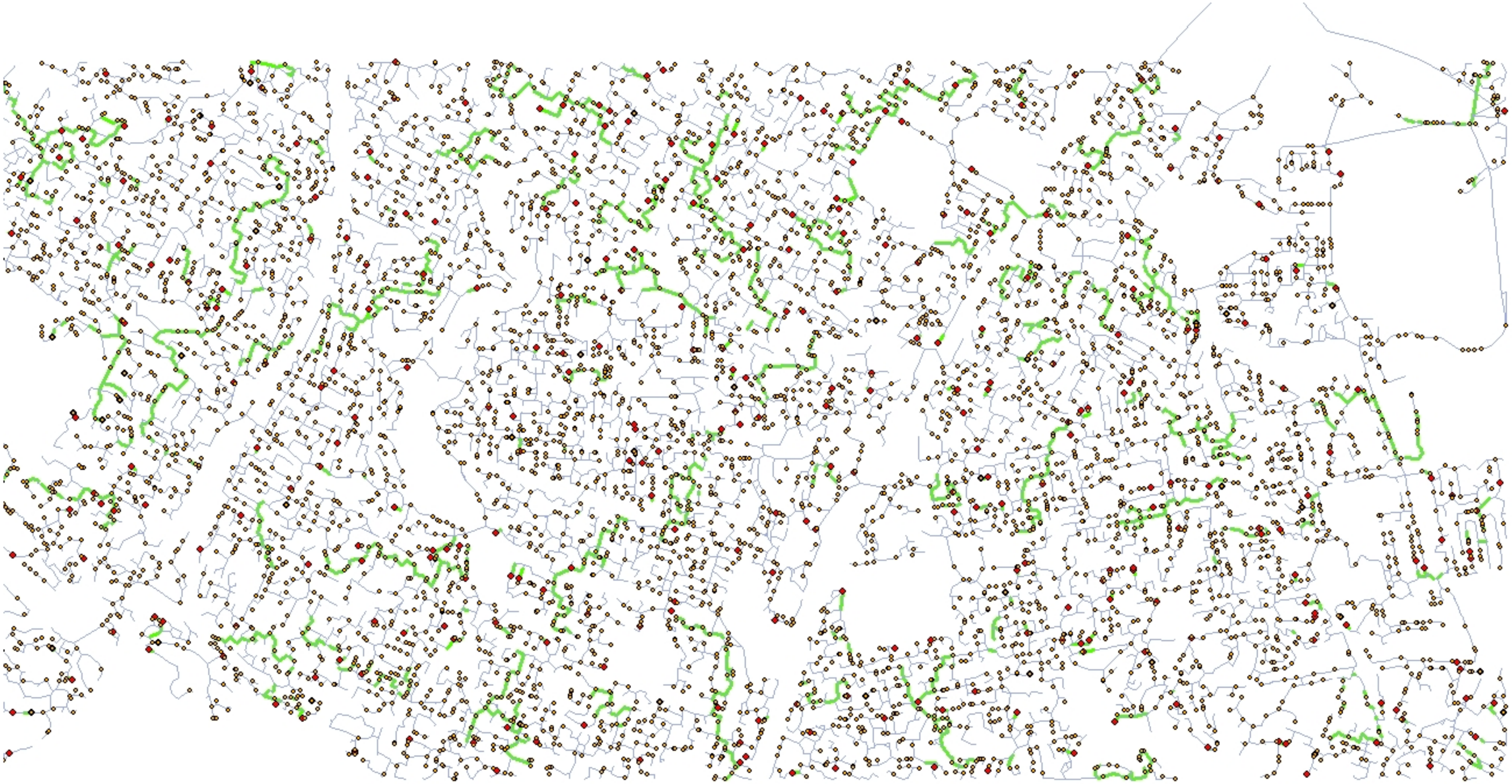
Source: MIT Solar Study

Reference Network Model



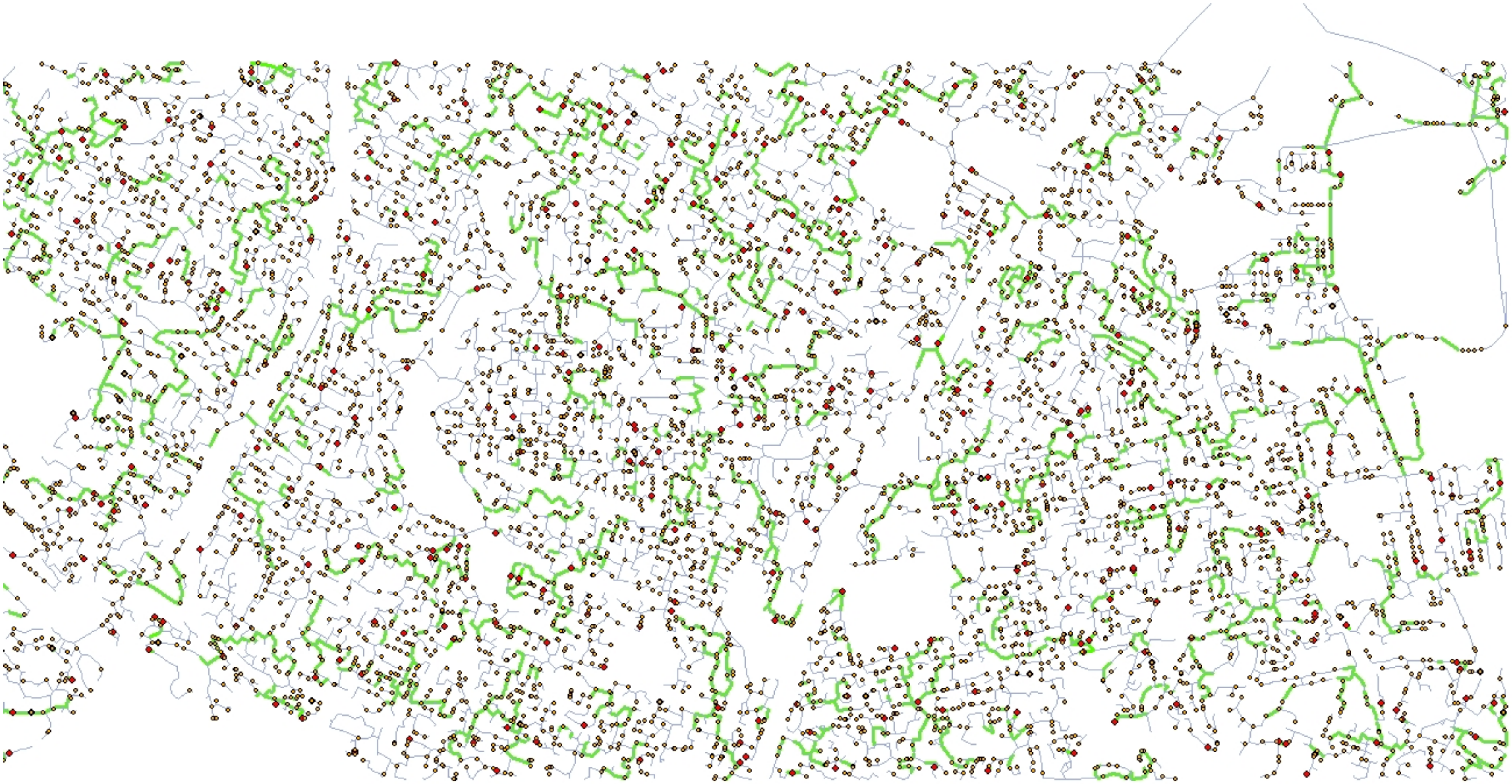
Source: MIT Solar Study

Reference Network Model



Source: MIT Solar Study

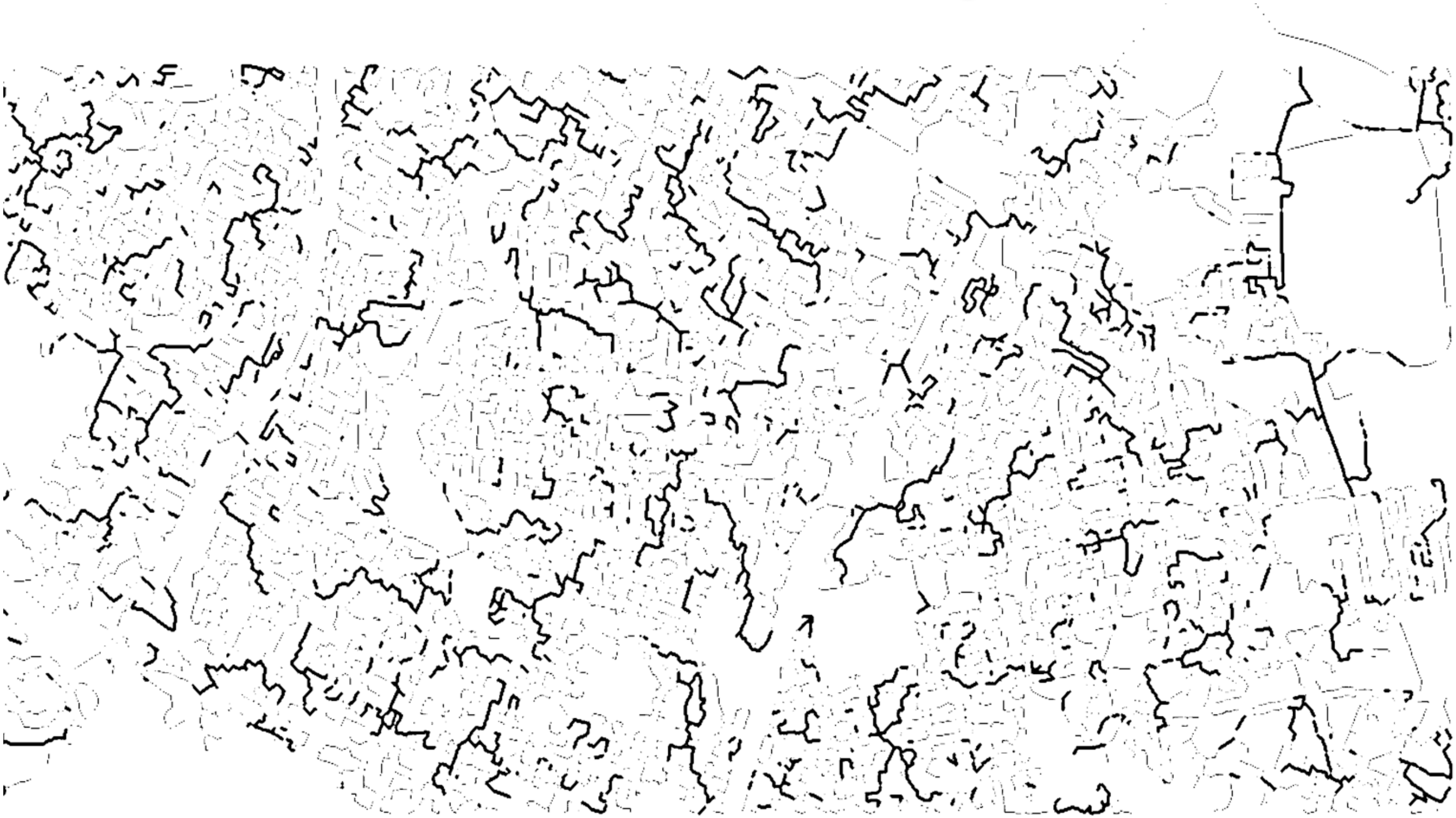
Reference Network Model



Source: MIT Solar Study

Reference Network Model

Distribution network reinforcements &their their associated costs can be significant



Source: MIT Solar Study

A toolkit for regulators & policy makers

Predicting the future? Rather a tool-kit

The recommendations in this study constitute a "toolkit" that is **robust to the uncertain changes** now underway and **capable of facilitating the emergence of an efficient portfolio of resources**, both distributed and centralized, to meet the needs of a rapidly evolving electricity sector.

Thank you for your attention

Stay tuned, December 15th, 2016…

http://energy.mit.edu/research/utility-future-study/